City of Boulder

TMP 2014

Transit Modal Plan

Appendix D: Fleet and GhG Scenario Analysis

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APPENDIX D TRANSIT FLEET AND GHG REDUCTION ANALYSIS

INTRODUCTION

This document describes the methodology and results of analysis of greenhouse gas (GhG) emissions reductions possible through changes in the transit system, including transition to cleaner fuel/energy sources for the transit fleet. It is organized into the following sections:

- Analysis Scenarios
- Methodology
- Results
  - Transit Fleet Emissions (for current year and 2035 scenarios and several fuel/energy alternatives)
  - Net Transit GhG Emissions (accounting for VMT avoided by riding transit)
- Key Findings

ANALYSIS SCENARIOS

Transit Scenarios

Various transit vehicle fleet scenarios were analyzed to show the range of GhG reduction possible through fleet change. Scenarios included two time horizons:

- **Current Year Boulder County Transit System.** GhG emissions from current transit vehicle miles traveled (VMT) in Boulder County were estimated based on the current fleet of diesel transit vehicles and several fuel/energy alternatives.
- **2035 Transit Scenario.** A future-year transit scenario was adapted from the transit scenarios analyzed as part of the TMP.[1] It represents a substantial increase in service investment and transit VMT by 2035. GhG emissions were estimated using a similar set of fuel/energy alternatives as was analyzed for the current system.

[1] EIA 2014 Energy Outlook, Freight Transportation Energy Use, Heavy Diesel Fuel Efficiency, Reference Case, 2013-2035. See Figure D-3 for methodology details.

Fuel/Energy Alternatives

These scenarios were analyzed under several transit fuel/energy alternatives, intended to reflect a range of options:

- **A. Full Diesel Bus Fleet.** The diesel analysis assumes a complete fleet comprised of "clean" diesel vehicles. The current year scenarios use the existing fuel economy numbers for "clean" diesel buses. The 2035 scenarios use a more conservative 18.4% increase in 2035 transit fleet fuel economy based on the U.S. Energy Information Administration's (EIA) Annual Energy Outlook Reference Case for Heavy Diesel.[2]
- **B. Diesel Hybrid-Electric Bus Fleet.** The diesel hybrid-electric scenario assumes a fleet comprised entirely of hybrid-electric transit buses for all routes. Hybrid-electric buses have been adopted by RTD on a number of routes and are a familiar technology for transit operators and maintenance personnel. The vehicles combine a small conventional diesel hybrid-electric engine to charge an electric propulsion system plus regenerative braking. Fuel economy numbers are drawn from the Federal Transit Administration's (FTA) Altoona test results with more aggressive assumptions (23.4%) for transit fleet fuel efficiency improvement by 2035 based on the EIA Extended Policies Case for Heavy Diesel. [3] This case assumes that policies mandating increased efficiency for heavy vehicles will be extended into the future. The Extended Policies case includes an assumption that efficiency standards do not "sunset" as currently legislated.
- **C. Electric and Hybrid-Electric Mix**. Employing a mix of full-electric and diesel hybrid-electric transit vehicles, the Electric and Hybrid-Electric Mix alternative models full-electric buses on local routes and diesel hybrid-electric buses on regional routes. Short ranges limit the current generation of electric buses. Emissions numbers are drawn from the Altoona test results for diesel hybrid-electrics and full-electric buses, plus a source emissions calculation using the existing Xcel Energy – PSCo power supply mix and a low carbon power supply mix for illustrative purposes. A more aggressive fuel efficiency improvement is assumed for these vehicle types.
- **D. Full-Electric Bus Fleet.** The all-electric bus fleet scenario suspends existing range limitations to test the greenhouse gas savings achievable through a fully electric bus fleet, today and in the year 2035. Current year numbers for electric vehicle GhG emissions reflect source emissions from the current Xcel Energy – PSCo power supply mix[4] and a low-carbon power supply mix for illustrative purposes. Future-year electric vehicles GhG emissions similarly include a sensitivity test of the current power supply mix, and a potential low-carbon energy supply mix. A more aggressive fuel efficiency improvement is assumed for these vehicle types.

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[2] EIA 2014 Energy Outlook, , Freight Transportation Energy Use, Heavy Diesel Fuel Efficiency, Extended Policies Case, 2013-2035. See Figure D-3 for methodology details.

[3] FTA Altoona testing, average R1015 (New Flyer XDE40) and R1007 (Orion VII EPA 10); average of measured, Manhattan NY, Orange County CA, and UDDS scenarios; EIA 2014 Energy Outlook.

[4] Xcel Energy PSCo, 2012 Owned and Purchased Energy, accessed online: http://www.xcelenergy.com/About_Us/Our_Company/Power_Generation/Power_Generation_Fuel_Mix_-_PSCo

These alternatives were developed with several considerations in mind:

- The projected 40% improvement in light-duty vehicle (LDV) fleet fuel efficiency by 2035 represents an aggressive conversion based on federal standards, and assumes continued penetration of hybrid technology in the LDV fleet.
- Federal standards for heavy-duty vehicles are still evolving and there is no specific EIA projection for buses. Different rates of increased efficiency were assumed for different bus technologies. Innovations likely will increase standard diesel-powered transit vehicle efficiency (i.e., Alt. A). However, a hybrid-electric fleet (i.e., Alt. B), reflects continued adoption of hybrid technology as many transit agencies are doing today and is a more appropriate comparison to light-duty vehicle efficiency trends. The other alternatives (C and D) test more aggressive moves to cleaner transit vehicles, represented by a blended hybrid-electric and electric transit fleet or an all-electric transit fleet.
- It is assumed in Alt. D that a full-electric fleet could be supported by battery technology for all types of routes by 2035, however it should be noted that other market-driven technologies (see sidebars on the following pages) will influence the efficiency and GhG benefits for the technologies included in this analysis. These technologies may supplant the options considered with alternatives that have comparable emissions benefits. For example, hydrogen fuel cells are an evolving technology that could be a viable future path to reducing transit fleet emissions.

Leading Edge Transit Technology

Electric Bus

What: Manufactured by Proterra and BYD in the United States, electric buses are ready for fleet integration today. Electric buses from Solaris and other manufacturers do not meet Buy America requirements.

Benefits: Quiet, smooth operations. Fast acceleration and regenerative braking work well for transit. On-route charging possible with contactless overhead infrastructure.

Negatives: Expensive, vehicles cost between 25-50% more than conventional buses. Shorter range, often only 50 miles. Infrastructure upgrades for on-route charging are expensive. Depending on source of electricity, carbon footprint may remain large.

Case examples: Proterra used by Foothill Transit in the San Gabriel Valley of California and San Joaquin RTD. Long Beach, California awaiting delivery of BYD buses.

Proterra ecoliner, charging while in-service during a stop in San Joaquin, California.

Source: wikipedia

Proterra ecoliner, Foothill Transit, San Gabriel, Calif.

Source: flickr user lucian400

Hydrogen Fuel Cell Hybrid Bus

What: Electrically propelled buses using proton exchange membrane fuel cells to convert hydrogen gas to energy. Hydrogen fuel cell buses offer performance and range similar to diesel vehicles without noxious emissions.

Benefits: Only water vapor and heat emissions. Quick refueling, sometimes using existing compressed natural gas facilities. Not as range-limited as electric buses.

Negatives: Expensive, a five-year pilot in Whistler, British Columbia was five times more expensive than diesel. More frequent maintenance. Difficult and expensive to get renewable hydrogen. May be energy-intensive to extract hydrogen for use.

Case examples: Ten pilot programs are taking place around North America including Cleveland's RTA, AC Transit's HyRoad, and SunLine Transit Agency in Riverside County, California.

Cleveland RTA's hydrogen fueling station.

Source: NASA.gov

Hydrogen-powered Credo E-Bone concept bus designed by Peter Simon. Composite body used to reduce weight.

Source: green.autoblog.com

Emerging Transit Technology

Electric School Buses

Conversion of school buses to electric is an ideal use of electric vehicle technology:

- School bus routes are often short
- Buses spend most of the day in depots and not in use
- Frequent stops help charge batteries through regenerative braking
- Current school buses emit heavy tailpipe emissions in residential neighborhoods.

Air Resource Board of California's ZEBRA demonstration school bus.

Source: wikipedia

Advances in Materials

- Lightweight vehicle construction materials such as carbon fiber and composites allow transit vehicles to be more fuel-efficient.
- Recyclable materials such as steel, aluminum, and some plastic reduce the overall environmental footprint of transit vehicles.
- Transit vehicles constructed with recycled post-consumer waste materials may reduce the environmental impact of the vehicles.

Alcoa Aluminum produces the all-aluminum space frame for the BYD electric bus. Total body weight is reduced by 40%, nearly one ton, versus steel.

Source: Alcoa.com

e-Bus Rapid Transit (e-BRT)

Siemens Mobility is developing an integrated e-BRT vehicle system that incorporates electric propulsion, short charging sequences at stops, and an electronic guidance system. The system uses an advanced version of ultra rapid energy transfer, which may take as little as 20 seconds.

Using a retractable pantograph-like arm, the Siemens e-BRT will draw intense 20 second charges at each stop.

Source: siemens.com

METHODOLOGY

This section provides details on the methodology and assumptions used in this analysis.

Fleet Emissions

Overview

The following steps were used to compute the existing metric tons of CO2 emitted from transit vehicles for each current and future-year fleet scenario:

STEP 1: Calculate fuel consumption.

$$Total\ vehicles\ miles\ traveled\ \div Average\ Fuel\ Economy\ (mpg) =\ Gallons\ of\ fuel\ used$$

- The number of total transit vehicle miles traveled (daily weekday and weekend) was compiled for each route, from RTD's 2012 Service Recap report (August 2012). For the future year scenario, transit VMT was based on a refined version of the 2035 scenario developed for the TMP.
- The gallons of fuel consumed was calculated based on fuel efficiency assumptions for the predominant vehicle type used for each route, e.g., 30- or 40-foot transit bus or over-the-road (OTR) coach. These assumptions were drawn from a variety of government sources, primarily the EIA database and calculations for RTD vehicles in operation from FTA Altoona testing fuel economy numbers.

STEP 2: Calculate CO_2 equivalent emissions (CO_2e).

$$Gallons\ of\ fuel\ used\ \times CO_2\ emissions\ per\ gallon = Daily\ CO_2\ emissions$$

- CO_2 emissions for the fleet scenarios was calculated by applying a carbon-equivalent emissions factor per gallon of fuel (or fuel-equivalent energy) consumed per transit vehicle miles traveled. All CO_2 calculations were divided by 0.988 to yield a CO_2-equivalent (CO_2e) value.

STEP 3: Calculate electric vehicle CO_2 equivalent emissions (CO2e).

For electric vehicle types, a source emissions factor for the power mix was applied, representing a more accurate and "tunable" CO_2e emissions factor than using only the diesel fuel emissions equivalent number. CO_2e was calculated for electric buses using the FTA's Altoona average diesel fuel economy equivalent and the kilowatt hours (kWh) per mile averages from the ProTerra bus trial. Scenarios with the existing mix of coal, natural gas, and "low carbon" sources and a future scenario with 100% "low carbon" sources were used to calculate the source emissions from power generation for the electric fleet.

Detailed Assumptions

Assumptions and metrics are detailed in the following tables. Figure D-1 lists emissions factors that identify the quantity of CO2 emitted per unit of fuel or energy consumed.

Figure D-1 CO2 Emissions Factors

Metric	Assumptions	Source
CO_2 emissions from a gallon of diesel	10,180 g/gallon of CO_2	U.S. EPA, Greenhouse Gas Emissions from Typical Passenger Vehicles, http://www.epa.gov/otaq/climate/documents/420f11041.pdf
Average Emissions from *Coal* burning power plants, with scrubbers	1,001 g/kWh of CO_2	http://www.eia.gov/tools/faqs/faq.cfm?id=74&t=11
Average Emissions from *Natural Gas* burning power plants	469 g/kWh of CO_2	http://www.eia.gov/tools/faqs/faq.cfm?id=74&t=11
Average Emissions from *Wind/ low carbon energy* power	28.6 g/kWh of CO_2	http://www.eia.gov/tools/faqs/faq.cfm?id=74&t=11

CO2 emissions from electricity generation vary based on the sources used to generate the electricity. Figure D-2 describes current and future energy source profiles, including a future "low-carbon" energy mix.

Figure D-2 Electricity Energy Source Profiles

Power Source Mix	Current Energy Mix		Low Carbon Energy Mix	
Type	%	g CO_2e/ kWh	%	g CO_2e/ kWh
Coal	60%	607.9	0%	0
Natural Gas	22%	104.4	0%	0
Wind, solar, and other low carbon sources	18%	2.2	100%	12.2
TOTAL	100%	705.94	100%	12.2

Figure D-3 identifies fuel economy assumptions. For 2035, a 12% improvement in diesel fuel economy is assumed in the analysis.[5]

Figure D-3 Fuel Economy Assumptions

Fuel/Energy Type	Average Fuel Economy (MPG or MPGe) [1]			Source
	2013	% Improvement [2,3] 2013-2035	2035	
Diesel (clean diesel, B20, B100)	3.14	18.4%	3.72	Average of GREET and EPA EIA data. Assumed 2035 efficiency improvement based on EIA 2014 Reference Case for Heavy Diesel.[2]
Diesel HEV	5.74	23.4%	7.08	FTA, Altoona testing, AVG R1015 and R1007; AVG of measured, Manhattan, Orange CO, and UDDS scenarios. Assumed 2035 efficiency improvement based on EIA 2014 Extended Policies Case for Heavy Diesel.[3]
Electric Bus (MPGe)	20.84 [a, b]	23.4%	25.72	FTA, Altoona Testing, Diesel Fuel Equivalent, Proterra electric bus, PTI-BT-R1305-P. Assumed same level of 2035 efficiency improvement as hybrid.
Coach Transit Bus	4.06	18.4%	4.81	FTA, Altoona Testing: AVG Blue Bird Express 4500 Commute, Arterial, CBD Phase Consumption (3.37) and AVG MCI 102D3 3-phases (4.75). Assumed same level of 2035 efficiency improvement as standard diesel.

Notes: (1) Electric Bus Fuel Economy drawn from EPA standard Miles per Gallon Equivalent (MPGe). More information: http://www.epa.gov/carlabel/electriclabelreadmore.htm. Actual MPGe number calculated by FTA Altoona Test Center. (2) 18.4% 2035 fuel efficiency improvement assumed for clean diesel, electric, and over-the-road coaches (3) 23.4% fuel efficiency improvement assumed for diesel hybrid-electric vehicles. (a) Electric bus assumed similar fuel efficiency improvements as heavy-duty diesel fuel efficiency improvement of 18.4% by 2035 (EIA). (b) Based on 1.81 kWh/mile.

[5] Diesel fuel economy numbers drawn from the average diesel bus fuel economy of the 2013 GREET (Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model) and 2012 Clean Air Task Force's Clean Diesel versus CNG Buses: Cost, Air Quality, & Climate Impacts Report (http://www.catf.us/resources/publications/files/20120227-Diesel_vs_CNG_FINAL_MJBA.pdf).

2035 emissions for transit buses is based on a 18.4% fuel efficiency improvement assumed for clean diesel, electric, and over-the-road coaches and a 23.4% fuel efficiency improvement assumed for diesel-hybrid-electric vehicles; based on an EIA projection for all heavy-duty freight vehicles. Source: EIA Annual Energy Outlook 2014 with projections to 2040, http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf

This is inherently conservative as there is no specific EIA projection for buses, but innovations likely will increase standard diesel-powered transit vehicle efficiency beyond this level. A more aggressive electric light-duty vehicle scenario could be paired with either the third fleet scenario (balance of electric vehicles for local routes and hybrid-electrics for regional routes) or an additional all-electric transit fleet scenario that could be supported by improved battery technology by 2035 (or an alternative technology with comparable emissions benefits).

RESULTS

This section presents the potential transit fleet emissions reductions attainable with the fuel/energy alternatives for both current and 2035 scenarios. It then provides estimates of net GhG emissions, accounting for avoided VMT from transit riders.

Transit Fuel/Energy Source Shift (Boulder County)

Figure D-4 provides results of the alternative fleet energy source analysis. It should be noted that the results include only RTD routes, not University of Colorado (CU) or Boulder Valley School District (BVSD) operated services. The table lists CO_2 emissions estimates for alternative fleet scenarios for the current transit system and a 2035 Transit Scenario.

Current Year

The top portion of Figure D-4 lists CO2 emissions estimates for alternative fleet scenarios for a current-year transit system scenario including total emissions for each fuel/energy alternative and the difference from the base case (A). Base emissions are about 25,000 MT CO_2e and alternative fleet energy sources and fuel types could reduce transit emissions by 38% to 82%. Given the current electricity energy source mix for Boulder, fully electric transit vehicles do not achieve a significantly greater reduction in emissions compared to hybrid vehicles. However, a blended electric/hybrid-electric vehicle fleet (C2) or a full electric fleet (D2) would reduce emissions compared to a hybrid fleet (B) under the clean energy portfolio currently being considered as part of Boulder's formation of a municipal utility.

2035 Transit Scenario

The bottom portion of Figure D-4 lists CO2 emissions estimates for a 2035 transit fleet scenario.

- In 2035, assuming a significant increase in transit service, maintaining a predominantly diesel transit fleet would increase transit vehicle emissions to 56% from the current level, even with an assumed 18.4% increase in 2035 fleet diesel fuel efficiency (for standard diesel vehicles). This is due to the increase in the number of transit vehicle miles in the 2035 scenario.
- As described in the next section, the increase in transit vehicle emissions in (A) would be partially offset by emissions reductions from increased ridership and passenger vehicle-miles avoided. However, due to increased passenger vehicle fuel efficiency over time there would be a decline in the emissions reduced per passenger vehicle-mile converted to transit.
- A hybrid-electric (HEV) fleet (B) and a blended electric/HEV fleet (C1) or a full electric fleet (D1) with the *current energy source mix* would all achieve approximately the same reduction in transit fleet emissions—by 45% from 2035 base diesel fleet scenario (A) emissions.
- A blended fleet of electric and HEV vehicles with a *low-carbon energy source mix* (C2) would reduce emissions by 55% from base diesel fleet scenario (A) emissions.
- A full electric fleet with a *low-carbon energy source mix* (D2) would reduce emissions by 83% from base diesel fleet scenario (A) emissions.

Figure D-4 Annual Transit GhG Savings from Cleaner Fuel/Energy Adoption, MT CO_2e, Current and 2035 Fleet Scenarios

Current Year (2013 Base)

Comparisons to Current Scenario Base Emissions								
Fuel Type	Metric Tons of CO2e Emissions/ Year	Difference from Diesel Fleet (A)	Difference from Hybrid-Electric Fleet (B)	Difference from Electric and HEV (Current Mix) (C1)	Difference from Electric and HEV (Low Carbon) (C2)	Difference from Full Electric (Current Mix) (D1)	Difference from Full Electric (Low Carbon) (D2)	% Change From to Current Year Diesel Fleet
A. Diesel	25,530	0	9,910	9,890	15,040	9,870	20,830	N/A
B. Hybrid-Electric (HEV)	15,620	-9,910	0	-20	5,130	-40	10,930	-39%
C1. Electric/ HEV (Current Energy Mix)	15,640	-9,890	20	0	5,150	-20	10,950	-39%
C2. Electric/ HEV (Low Carbon Energy Mix)	10,490	-15,040	-5,130	-5,150	0	-5,170	5,790	-59%
D1. Full electric (Current Energy Mix)	15,660	-9,870	40	20	5,170	0	10,970	-38%
D2. Full electric (Low Carbon Energy Mix)	4,700	-20,830	-10,930	-10,950	-5,790	-10,970	0	-82%
Fleet VMT/YEAR	8,703,000							

2035 Transit Scenario

Comparisons to 2035 Scenario Base Emissions									Current Base
Fuel Type	Metric Tons of CO2e Emissions/ Year	Difference from Diesel Fleet (A)	Difference from Hybrid-Electric Fleet (B)	Difference from Electric and HEV (Current Mix) (C1)	Difference from Electric and HEV (Low Carbon) (C2)	Difference from Full Electric (Current Mix) (D1)	Difference from Full Electric (Low Carbon) (D2)	% Change from 2035 Diesel Fleet	% Change from Current Year Diesel Fleet
A. Diesel	39,870	0	17,960	17,940	22,010	17,900	33,280	N/A	56%
B. Hybrid-Electric (HEV)	21,910	-17,960	0	-20	4,050	-60	15,320	-45%	-14%
C1. Electric/ HEV (Current Energy Mix)	21,930	-17,940	20	0	4,070	-40	15,340	-45%	-14%
C2. Electric/ HEV (Low Carbon Energy Mix)	17,860	-22,010	-4,050	-4,070	0	-4,110	11,270	-55%	-30%
D1. Full electric (Current Energy Mix)	21,970	-17,900	60	40	4,110	0	15,380	-45%	-14%
D2. Full electric (Low Carbon Energy Mix)	6,590	-33,280	-15,320	-15,340	-11,270	-15,380	0	-83%	-74%
Fleet VMT/YEAR	15,064,000								

* Current mix of electricity: 60% coal with scrubbers, 22% natural gas, and 18% wind and other 'green sources'
** "Low carbon mix" is an average CO2e (24.8g) output of bio-mass (18g), Solar PV (46g), Solar CSP (22g), and wind (12g), adjusted for CO2 equivalency. Source: Moomaw, W., et al, 2011: Annex II: Methodology. IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, et al [eds.]], Cambridge University Press, Cambridge, New York, NY. http://srren.ipcc-wg3.de/report/IPCC_SRREN_Annex_II.pdf

Net Transit GhG Emissions

This section presents net transit GhG emissions for the current and future transit fleet scenarios and fuel/energy alternatives described in the previous section.

Current

Figure D-5 shows 2014 City of Boulder GhG projections (from the Transportation GhG Workbook). For the current-year scenario, projections assume a complete fleet transition to the modeled fuel source (in practice, a transition would likely be realized through phased fleet replacement, which is assumed in the 2035 scenario).

- **Transit Fleet VMT and Emissions.** Figure D-5 integrates transit fleet emissions scenarios from the above fleet analysis (Figure D-4); current year transit emissions are estimated at about 25,500 MT CO_2e for RTD and Via. See Row E (base) and Rows H to L (fuel/energy alternatives). These scenarios would reduce transit emissions (RTD/Via only) by between 39 and 82% (consistent with the above analysis).
- **Passenger VMT Avoided.** Figure D-5 integrates data from the Transportation GhG Workbook estimating over 35,000 MT CO_2e are avoided from existing transit in Boulder County (annual, including weekends).[6] These savings represent a reduction of 138% of RTD/Via transit emissions. See Row M.
- **Net GhG Emissions.** The final six rows of Figure D-5 (Rows N to S) show net emissions benefits from transit for the fuel/energy alternatives described above including GhG avoided from transit passenger vehicle trips avoided. These net reductions range from nearly 10,000 to 30,500 MT CO_2e relative to the current-year base scenario, or reductions of 38 to 120%. They represent a 4 to 13% reduction in the City of Boulder 2014 Transportation GhG forecast.

[6] A parallel analysis with a different methodology yielded similar results for weekday ridership only: There are currently about 8.9 million annual weekday rides on transit in Boulder County (based on the 2012 data used in the TMP analysis). If all these rides were converted to single- and multiple-occupant vehicle trips this would result in over 64 million additional vehicle miles traveled (VMT) annually. Assuming current average light-duty fleet fuel efficiency of 20.9 miles per gallon (MPG), these VMT would result in emissions of over 27,000 metric tons (MT) of CO_2 annually. This analysis assumed average vehicle occupancy of 1.3 and the average vehicle miles traveled (VMT) saved per ride applying data and methodology used in the Community-Wide Eco Pass Feasibility Study. Fuel efficiency assumptions were based on the EIA 2013 Reference Case that was current at the time this analysis was conducted.

Figure D-5 City of Boulder GHG Forecast, 2014, and Reductions due to Passenger VMT Avoided and Transit Fleet Fuel/Energy GhG Reductions

		Annual VMT	*% VMT*	*Annual GhG (MT)*	% Reduction of Transit-Related GhG Emissions (c)	% of Total City of Boulder 2014 Transportation GhG Forecast (d)
A.	Non-Resident Employee (a)	190,848,000	33%	70,033	-	29%
B.	Resident (walk/bike) (a)	301,105,728	52%	110,493	-	46%
C.	Student (walk/bike) (a)	70,200,000	12%	25,760	-	11%
D.	TOTAL WITHOUT TRANSIT	562,153,728	98%	206,286	-	86%
E.	Transit - RTD/VIA (b)	8,703,000	2%	25,500	-	11%
F.	Transit - CU/NCAR/BVSD (a)	3,269,500	1%	8,400	-	3%
G.	TOTAL WITH TRANSIT	574,126,200	100%	240,200	-	100%
	GHG REDUCTIONS (ENERGY OR RIDER VMT AVOIDED)					
H.	Reduction with Hybrid-Electric Fleet			-9,900	-39%	-4%
I.	Reduction with Electric/HEV with existing energy mix			-9,900	-39%	-4%
J.	Reduction with Electric/HEV with low-carbon mix			-15,000	-59%	-6%
K.	Reduction with Full Electric with existing energy mix			-9,800	-38%	-4%
L.	Reduction with Full Electric with low-carbon mix			-20,800	-82%	-9%
M.	Transit Riders VMT/GhG Avoided (a)			-35,200	-138%	-15%
	NET RTD/VIA TRANSIT GhG					
N.	w/ Diesel Fleet and Rider VMT Avoided			-9,700	-38%	-4%
O.	w/ Hybrid-Electric Fleet and Rider VMT Avoided			-19,600	-77%	-8%
P.	w/ HEV/Electric existing energy mix and Rider VMT Avoided			-19,600	-77%	-8%
Q.	w/ HEV/Electric low-carbon mix and Rider VMT Avoided			-24,700	-97%	-10%
R.	w/ Full Electric existing energy mix and Rider VMT Avoided			-19,500	-76%	-8%
S.	w/ Full Electric low-carbon mix and Rider VMT Avoided			-30,500	-120%	-13%

Notes: (a) From GhG Transportation Data Book (b) From fleet analysis or revised calculations. (c) Percentages are relative to the RTD/Via transit emissions only. (d) Percentages are relative to the total City of Boulder Transportation GhG Forecast.

2035 Transit Scenario

The Renewed Vision for Transit would increase operating and capital investment in local and regional transit services, such as improved local circulation between Boulder Junction and the University of Colorado campuses and additional service on regional routes between Boulder and other parts of Boulder County. A 2035 transit scenario was adapted from several transit scenarios that were developed as part of the TMP for comparative purposes. With this level of investment, transit ridership is projected to increase by over 100% by 2035.[7]

[7] This scenario is not constrained to TMP funding scenarios or the Transit Action Plans, however some elements of the original scenarios (see Transit Scenario Analysis Report) were not included. The additional investment in transit would result in a projected 19.3 million annual weekday transit rides by 2035. Ridership estimates were based on 2030 population and growth projections for the County, interpolated to 2035, and 2035 population and growth projections for the City, at the TAZ level.

Figure D-6 provides estimates of net GhG reductions based on the 2035 transit scenario.

- **Transit Fleet VMT and Emissions**. With a significant increase in the level of transit service, transit VMT and GhG emissions would increase (from 25,500 to nearly 40,000 MT CO_2e) if the fleet composition remains similar to today, even with an assumed 18.4% increase in transit fleet fuel efficiency in the baseline clean diesel case. The five fuel/energy alternatives analyzed in addition to the base case would decrease fleet emissions by 45 to 83%) relative to the 2035 base case and their share of transportation GhGs by between 6 and 12%. See Row E (base) and Rows H to L (fuel/energy alternatives).
- **Passenger VMT Avoided**. Emissions of about 40,000 MT of annual CO_2e would be avoided (Row M) due to increased transit ridership under the 2035 transit scenario. This estimate is based on assumptions for average VMT savings per ride[8], and reduces annual emissions by over 40,000 MT CO_2e. (offsets base case transit emissions without substantial additional reductions). This assumes increased passenger vehicle fuel efficiency over time as more fuel-efficient vehicles are introduced and older, less fuel-efficient vehicles are retired; the EIA Annual Energy Outlook projects light-duty vehicle (LDV) fleet fuel efficiency of 34.1 MPG in 2035, compared to 20.9 MPG in 2012.[9] As a result, the emissions savings per passenger-mile served on transit will decline.

  However, the GhG benefits supported by transit reach beyond transportation, contributing to and supporting land uses and development that reduce VMT and have a smaller GhG footprint. Transit plays a key role in shaping built form and compact, walkable neighborhoods. Residents in walkable neighborhoods drive less not only by walking more but by using transit more often.

Net GhG Emissions. The last six rows (N to S) of Figure D-6 show net GhG emissions. Given increased passenger vehicle fuel efficiency, a diesel fleet scenario would result in an increase in net transit emissions. However, a hybrid-electric, electric/HEV, or full electric fleet scenario with a low-carbon mix would provide net reductions of 18,300 MT CO_2e to 33,600 MT CO_2e annually relative to the 2035 base scenario, or reductions of 46 to 84% of transit emissions. This represents a 6 to 12% reduction in the City of Boulder 2035 Transportation GhG Forecast.

[8] The Community-Wide Eco Pass Feasibility Study methodology was applied to estimate the VMT per ride along existing transit corridor segments. For new corridor segments where VMT could not be inferred from existing route data, VMT was estimated based on 60% of the corridor segment distance for local trips and 80% of the corridor segment distance for regional trips. Transit was projected to result in savings of over 135 million annual VMT.

[9] EIA 2013 Reference Case that was current at the time this analysis was conducted.

Figure D-6 City of Boulder GHG Forecast, 2035, and Reductions due to Passenger VMT Avoided and Transit Fleet Fuel/ Energy GhG Reductions

		Annual VMT	% VMT	Annual GHG (MT)	% Reduction of Transit-Related GhG Emissions (c)	*% of Total City of Boulder 2035 Transportation GHG Forecast (d)*
A.	Non-Resident Employee	235,152,000	36%	86,290	-	31%
B.	Resident (walk/bike)	309,581,170	47%	113,603	-	41%
C.	Student (walk/bike)	94,500,000	14%	34,677	-	12%
D.	TOTAL WITHOUT TRANSIT (a)	639,233,170	97%	234,571	-	84%
E.	2035 Transit Scenario - Diesel (b)	15,064,200	2%	39,900	-	14%
F.	Transit - CU/NCAR/BVSD (a)	3,269,500	0%	8,400	-	3%
G.	TOTAL WITH TRANSIT	657,566,900	100%	282,900	-	100%
	GHG REDUCTIONS (ENERGY OR RIDER VMT AVOIDED)					
H.	Reduction with Hybrid-Electric Fleet			-18,000	-45%	-6%
I.	Reduction with Electric/HEV with existing energy mix			-18,000	-45%	-6%
J.	Reduction with Electric/HEV with low-carbon mix			-22,000	-55%	-8%
K.	Reduction with Full Electric with existing energy mix			-17,900	-45%	-6%
L.	Reduction with Full Electric with low-carbon mix			-33,300	-83%	-12%
M.	Transit Riders VMT/GhG Avoided (e)			-40,200	-101%	-14%
	NET RTD/VIA TRANSIT GhG					
N.	w/ Diesel Fleet and Rider VMT Avoided			-300	-1%	0%
O.	w/ Hybrid-Electric Fleet and Rider VMT Avoided			-18,300	-46%	-6%
P.	w/ HEV/Electric existing energy mix and Rider VMT Avoided			-18,300	-46%	-6%
Q.	w/ HEV/Electric low-carbon mix and Rider VMT Avoided			-22,300	-56%	-8%
R.	w/ Full Electric existing energy mix and Rider VMT Avoided			-18,200	-46%	-6%
S.	w/ Full Electric low-carbon mix and Rider VMT Avoided			-33,600	-84%	-12%

Notes: (a) From GhG Transportation Data Book, for 2035 (b) From fleet analysis or revised calculations. (c) Percentages are relative to the RTD/Via transit emissions only. (d) Percentages are relative to the total City of Boulder Transportation GhG Forecast. (e) Transit scenario estimate adapted for this analysis including an adjustment to account for weekend riders.

SUMMARY OF KEY FINDINGS

Key findings from this analysis include:

- Maintaining the status quo bus transit fleet (primarily diesel) would likely decrease the current net GhG emissions benefit from transit by 2035 due to increased transit service and increased passenger vehicle fuel efficiency. This would occur even with an assumed 18.4% efficiency improvement in standard transit vehicles. Based on the assumptions in this analysis, the benefit is small but still represents a net reduction in GhG emissions.
- Transitioning the transit fleet to cleaner fuel/energy sources will be necessary to increase net GhG emissions reductions from transit. This analysis evaluated several vehicle options ranging from current generation hybrid-electric and electric vehicles, including a blend of hybrid and electric vehicles. It also assumed continued fuel efficiency improvements in both standard diesel vehicles (e.g., lighter materials) and more substantial efficiency improvements in hybrid vehicle technologies (e.g., from regenerative braking).
- With the current electricity energy source mix in Boulder, a conversion to electric buses offers little overall benefit in reducing GhG emissions—comparable to converting to hybrid-electric vehicles. However, shifting to an electric bus fleet does reduce local emissions of various air pollutants while generating emissions at the energy source, e.g., coal or natural gas power plant.
- The analysis included a low-carbon energy source mix, as could be achieved with the clean energy portfolio currently being considered as part of Boulder's formation of a municipal utility, and demonstrated the sensitivity of GhG emissions benefits to the energy source for electric vehicles. Changing from the current energy mix to a low-carbon energy mix of wind, biomass, solar, and thermal significantly reduces the overall GhG emissions of the fleet, reducing 2035 emissions to 26% of the current level (74% reduction) and to 17% of the 2035 scenario estimate (83% reduction).
- Advances in vehicle and fuel technologies (e.g., hydrogen fuel cells) will be market-driven and are likely to both enhance the efficiency of the vehicle types analyzed and make additional clean fuel/energy options viable in the future. An all-electric transit fleet scenario may or may not be supported by battery technology by 2035, and Boulder may or may not be able to transition to a cleaner energy source mix by 2035, however an alternative technology is likely to be available that can provide comparable emissions benefits to the alternative analyzed.
- Transit also provides indirect GhG benefits, contributing to land use development patterns that support reduced VMT and have a smaller GhG footprint. Transit plays a key role in shaping built form and compact, walkable neighborhoods. Residents in walkable neighborhoods drive less not only by walking and biking more but by using transit more often. Two statistics from T4America highlight the opportunity to reduce GhG emissions by influencing the character of the built environment:
  - Eliminating one vehicle and using public transit can reduce a two-car household's carbon footprint by 25 to 30 percent.
  - Residents of the most walkable areas of the country drive 26 percent fewer miles per day than those living in the most sprawling areas.

  Pursuing transit, TDM, and land use strategies are all opportunities for the public sector to influence GhG emissions at a relatively low cost per net unit reduced.